

COMPUTERIZED MONITORING SYSTEMS

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STATISTICAL CONTROL METHODS IN GLASS BATCH PREPARATION PROCESS

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Statistic methods for quality control of raw materials and glass batches are considered. An algorithm for statistic control of the batch preparation process is proposed.

Statistical control of any technological process consists of correcting input and output process parameters based on sampling data to ensure adequate quality of finished product [1]. The adjustment of process parameters in the simplest cases can be implemented without participation of the personnel, i.e., by automatically maintaining the constancy of one or several parameters with a certain accuracy. Such systems may use deviation control, disturbance control, or a combined principle.

In automated or so-called “man-machine” systems an adjustment is performed with human participation based on statistical analysis of output parameters of the process.

The present study considers the use of statistical control methods in the process of glass batch preparation for sheet glass production at the Borskii Glass Works JSC.

The statistical control method consists of the following operations [2]:

- construction of a model of the batch preparation process;
- identifying processes and operations;
- analysis of the effect of the quality of raw materials and precision of individual operation on the batch quality;
- analysis of the efficiency of methods used to control the quality of raw materials;
- analysis of statistic control methods at production facilities;
- estimate of manageability of technological processes of material pretreatment and batch preparation;
- developing proposals for statistic control and regulation methods;
- experimental verification of the efficiency of proposals and implementation of these results in production.

The process of preparing glass batch in the general case consists of five interrelated operations [3] and constitutes a technological chain of transformations including acceptance and storage of raw materials, control and treatment of glass batch components, preparation of the batch, and its storage and transportation to the glass-melting furnace.

The input control of raw materials performed by the central plant laboratory and technical services is needed to establish the compliance of the quality of materials with standard requirements for the following parameters:

- chemical homogeneity and constancy of chemical composition;
- content of iron oxides;
- homogeneity and constancy of granulometric composition.

To estimate the dynamics of the fluctuations of material parameters from one batch to another, statistic acceptance control based on mathematical statistics is used. The quality is estimated based on the probability distribution density of the variations of the analyzed parameter for each material. One of the methods for estimating distribution density is the construction of a histogram in order to identify the probability distribution density law and to obtain the mathematical expectation and the dispersion of the controlled parameter values in the material.

By way of example, let us consider histograms constructed to estimate the quality of sodium sulfate (the content of the main material) in different delivery lots [4]. According to technological standard, the content of sodium sulfate converted to dry matter should be within the interval:

$$\Delta X = X_{\max} - X_{\min},$$

where $X_{\max} = 99.0\%$ and $X_{\min} = 97.3\%$ are the maximum and the minimum content of Na_2SO_4 in the material.

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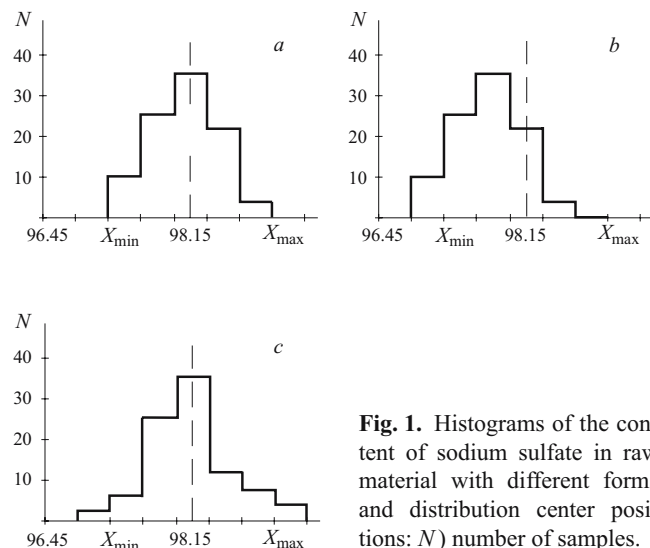


Fig. 1. Histograms of the content of sodium sulfate in raw material with different forms and distribution center positions: N) number of samples.

Based on the distribution of the content of the main substance on the histograms (Fig. 1) it is possible to find out whether the delivered material has a satisfactory quality level. For this purpose, based on determined tolerance, the number of intervals controlled, and the chosen number of samples (our example uses 100 samples of material), the distribution form and width are determined with respect to the admissible tolerance width.

The distribution form in Fig. 1a is satisfactory, as the left and the right sides are nearly symmetrical with respect to the distribution center, the distribution center coincides with the tolerance field center, and the distribution width is equal to the tolerance width. As the distribution domain coincides with the tolerance width, there is a probability of getting samples whose parameters are outside the established limits. In this case, it is advisable to tell the supplier of the need to stabilize the quality of material delivered.

In Fig. 1b the distribution form and center are shifted to the left, indicating a risk of receiving material with a decreased content of the main substance, below the bottom tolerance limit, which is inadmissible.

In Fig. 1c the distribution center coincides with the tolerance field center, but the distribution width exceeds the tolerance field width on both sides. Such material cannot be used in batch preparation, since it does not satisfy the established requirements on a stable content of the main substance.

TABLE 1

Parameter	Insoluble residue	Soda	Sulfates	Carbonates	Moisture	Temperature
Insoluble residue	1	-0.40	-0.19	-0.54	0.07	0.34
Soda	—	1.00	0.22	0.06	0.05	-0.25
Sulfates	—	—	1.00	0.04	-0.17	-0.03
Carbonates	—	—	—	1.00	-0.06	-0.30
Moisture	—	—	—	—	1.00	-0.14
Temperature	—	—	—	—	—	1.00

Thus, a histogram makes it possible to recognize the quality of material delivered. However, it does not provide numerical data on the distribution center, dispersion values, and symmetry between the left and the right distribution sides. To estimate the distribution center, the arithmetic mean and the dispersion, i.e., the mean quadratic deviation, are calculated.

In the cases when significant disturbances occur in the process or when correctives are introduced in the operating mode of the equipment, point estimates, such as the arithmetic mean and the standard deviation, are not sufficiently informative, since they cannot identifying the changes that have occurred. A stationary technological process may be also disturbed by other reasons: a variation in the properties of material used, design modifications of the technological equipment, etc. To identify such effects, we analyze the characteristic specifics of the probability distribution density of analyzed parameters using nonparametric approximation of the corresponding statistic distribution law.

The statistic analysis of the accuracy and stability of the batch preparation process, in addition to the analysis of the quality of material supplied, includes the solution of the following problems:

- comparing the mean values of the batch parameters and finished glass parameters to identify their random differences or regular correlations;
- comparing the dispersion (standard deviations) of the batch composition parameters;
- determining the correlation coefficient between the batch composition parameters,
- identifying the effect of the batch parameters on the variation of finished glass parameters, etc.

In statistic analysis of glass batch quality it is essential to know the independence of individual parameters, which simplifies the control process. To reveal these correlations, we carried out the correlation analysis of mean daily parameters of the batch quality for three years of performance of the batch-preparing division at the Borskii Glass Works. The matrix of the estimated pairwise correlation coefficients characterizing the tightness of the relations between the batch parameters is shown in Table 1.

Since the modulus of all estimated pairwise correlation coefficients does not exceed 0.7, the relationship between the batch quality parameters is considered weak [5] and can be neglected in developing corrective measures to stabilize the batch parameters.

The statistic parameters of batch preparation quality for the same period are given in Table 2.

It can be seen that the highest variability estimated based on the variation coefficients is observed in the content of sulfate, batch moisture, and batch temperature. Special attention should be paid to stabilizing such parameters.

At the same time, the table data do not provide an estimate of the variation of these parameters in time and do not allow taking preventive measures. Therefore, to estimate the accuracy and stability of the batch preparation process, plots

TABLE 2

Parameter	Mass content, %				Batch moisture, %	Batch temperature, °C
	insoluble residue	soda	sulfates	carbonates		
Mean value	61.81	17.88	0.81	20.52	4.45	45.80
Standard value	0.30	0.26	0.20	0.12	0.17	1.55
Variation coefficient, %	0.49	1.45	24.70	0.56	3.80	3.40

of the variation of the quality parameters in time are constructed, and the precision of the process is calculated from the formula

$$K_p = 6S_x / \Delta X,$$

where K_p is the precision coefficient of the process; ΔX is the analyzed parameter tolerance; and S_x is the mean quadratic deviation.

The deviation of the content of soda in the batch from the estimated values according to the results of statistical control in 2004 are shown in Fig. 2. It can be seen that the variation of soda content in time is characterized by the existence of a linear trend. The mathematical description of the trend is given in the field in Fig. 2 where the parameter “ x ” means the time in the day. On the average the content of soda during the year is 0.1% higher than the estimated value, which calls for attentive monitoring of the dosing-mixing lines.

Similar plots are constructed for other glass batch components and parameters (temperature, moisture, content of insoluble residue).

If a process is characterized by several parameters, for clarity the information is represented in a simple compact form of a circular radar plot [6].

The obtained statistic analysis data enable us to implement statistic control of the batch preparation process. The statistic control algorithm can be represented as follows:

- determination of the deviation of process parameters from prescribed standards using statistic methods for monitoring the precision and stability of the processes;
- choice of the most significant factors influencing decision making using a priori data on the process;
- evaluating these factors by correlation and multiple regression analysis;

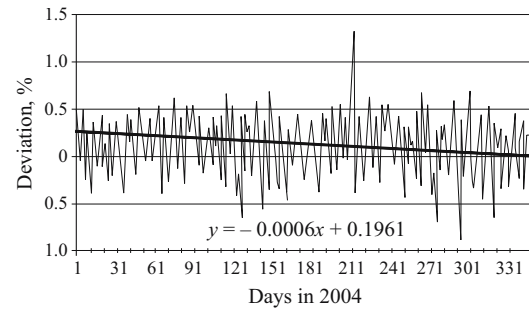


Fig. 2. Deviation of soda content in the batch from estimated values.

- improving the process by introducing corrective measures;

- obtaining the confirmation of results and processing new statistical data on the technological process;

The described statistical control methods can be efficiently implemented using personal computers and can be integrated in the quality management system of the batch preparation division for producing various glass products.

REFERENCES

1. V. I. Gissin, *Product Quality Management. Manual* [in Russian], Fenix, Rostov-na-Donu (2002).
2. R. I. Makarov, E. P. Khorosheva, K. Yu. Subbotin, and V. V. Efremkov, “Statistic control methods in the process of batch preparation for sheet glass production,” in: *Economics and Economic Equipment. Coll. Papers in 2 parts, Part 1* [in Russian], Vladimir (2005), pp. 186 – 194.
3. R. I. Makarov, E. R. Khorosheva, S. A. Ogryzkov, et al., “Quality management system of the batch preparation division,” *Steklo Keram.*, No. 7, 29 – 30 (2005).
4. R. I. Makarov, V. V. Tarbeev, E. P. Khorosheva, et al., *Quality Management of Sheet Glass (Float Process)* [in Russian], Izd-vo Assotsiatsii Stroitel. Vuzov, Moscow (2004).
5. R. A. Shmoilova (ed.), *A Practical Course in the Theory of Statistics* [in Russian], Finansy i Statistika, Moscow (1998).
6. E. P. Khorosheva, A. V. Molodkin, and V. V. Efremkov, “Use of a circular radar plot for analyzing the precision of technological process,” in: *New Methods for Developing Microelectronic Devices. Proc. 3rd Int. Sci. Techn. Conference* [in Russian], Vladimir (2004), pp. 135 – 137.